Development in the
Port Jackson shark embryo

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ABSTRACT

The Port Jackson shark (*Heterodontus portusjacksoni*) is an oviparous shark that breeds annually, between the months September and November. Temperatures in the field vary between 12°C to 22°C, producing long incubation periods of over 12 months. Incubation period in the laboratory is strongly temperature dependent, with embryos hatching after 400 days at 18°C and after 310 days at 22°C.

Each egg contains one embryo and is encased in a thick (1-2mm) pear-shaped collagenous casing that protects it. A freshly laid egg weighs 170.2 ± 5.0 g and contains a large yolk (38.6 ± 1.3 g), surrounded by a thick gelatinous albumen (70.7 ± 5.0 g). The capsule is 128.6 ± 2.4 mm long and weighs 60.9 ± 3.2 g at laying. The egg capsule is equipped with two respiratory slits, one located at either end of the case. From the time of laying up to the fourth month of incubation, the respiratory slits are plugged with a thick wedge of albumen, and the egg capsule is referred to as sealed. At four months, the plugs dissolve and the embryo is in direct association with the external seawater environment. The egg capsule is referred to as open.

Fifteen morphological stages are described for the developing embryo. In order to increase its effective surface area and therefore its aerobic capacity during the first four months of incubation, the embryo develops vascular external gill filaments, fins and yolk surfaces. The external gill filaments are extensions of the internal gill vasculature. They are thin walled and protrude from the gill openings into the albumen. When the egg capsule is open, the external gill filaments are reabsorbed back into the internal gill structure and the embryo uses its internal gills for respiration.

The embryo grows exponentially until it reaches a short plateau phase near hatching. By hatching it has transformed 77.7, 82.1 or 85.3% at 18°C, 20°C or 22°C, respectively, of the initial dry mass of yolk into hatchling tissue mass. From stage 12 onwards, the nutrients from the external yolk are simultaneously utilised for development and directed into an internal yolk sac which is attached directly to the spiral gut. By the time the embryo hatches as a self-sufficient fish, it has depleted all external yolk and virtually all internal yolk stores.
The initial yolk provides an average of 541.9 kJ of energy for the growth and maintenance of the embryo. The efficiency of growth, measured as the ratio of energy content of the hatchling to the energy content of the yolk, is high compared to embryos of other species (78.9, 83.4 and 86.7% at 18°C, 20°C or 22°C, respectively). The efficiencies are statistically similar at all temperatures despite the significant increase in incubation period at the lower temperatures, although a trend for reduced efficiencies at lower temperature was found.

Between egg capsule opening and hatching, oxygen consumption is correlated to the wet mass of the embryo plus yolk by the equation $\dot{V}_{O_2} = aM^b$ where $a = 53.6, 77.1, 173.4$ and $557.2$ and $b = 0.83, 0.77, 0.52$ and $0.22$ at 15, 18, 20 and 22°C, respectively.

As the embryo increases in mass, $Q_{10}$ values for $O_2$ consumption decrease from 7.9 at 5 g to 0.9 at 55 g near hatching. Stage 12 embryos maintain a steady $O_2$ consumption rate of 0.1 μmol $O_2$ min.g$^{-1}$ at a $P_{O_2}$ between 69 and 150 Torr. Below 69 Torr, $O_2$ consumption falls linearly with ambient $P_{O_2}$. The total $O_2$ consumed by the embryo increases as the incubation is lengthened at the lower temperatures. An embryo consumes 417, 285 and 267 mmol of $O_2$ at 18, 20 and 22°C, respectively. Hatchlings at all temperatures are of similar wet (54.9-58.8 g) and dry masses (16.1-17.7 g) and the cost of development is 25.9, 16.4 and 15.1 mmol $O_2$ per g dry hatching at 18°C, 20°C and 22°C.

The embryo actively ventilates the open egg capsule with vigorous scooping movements of the tail that draws water into and out of the egg capsule through the respiratory slits. The last 8 segments of the tail are curved upwards to form a spoon-shaped ending. Stage 10-12 embryos direct the flow of seawater in one side and out of the other side of the large respiratory slit located at the top of the egg capsule simultaneously, ensuring a fresh supply of oxygen. Stage 13-15 embryos are limited in the space available and simultaneously direct water in through the small respiratory slit at the bottom of the case, and out through the larger slit. A mean ventilation rate of 791 ml $O_2$ min$^{-1}$.kg$^{-1}$ is sufficient to sustain aerobic metabolism in the stage 12 embryo.